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Remote monitoring of biodynamic activity using electric potential sensors

C J Harland, R J Prance and H Prance

Centre for Physical Electronics and Quantum Technology, Department of Engineering and Design, School of Science and Technology, University of Sussex, Brighton, BN1 9QT, UK

c.j.harland@sussex.ac.uk

Abstract. Previous work in applying the electric potential sensor to the monitoring of body electrophysiological signals has shown that it is now possible to monitor these signals without needing to make any electrical contact with the body. Conventional electrophysiology makes use of electrodes which are placed in direct electrical contact with the skin. The electric potential sensor requires no cutaneous electrical contact, it operates by sensing the displacement current using a capacitive coupling. When high resolution body electrophysiology is required a strong (capacitive) coupling is used to maximise the collected signal. However, in remote applications where there is typically an air-gap between the body and the sensor only a weak coupling can be achieved. In this paper we demonstrate that the electric potential sensor can be successfully used for the remote sensing and monitoring of bioelectric activity. We show examples of heart-rate measurements taken from a seated subject using sensors mounted in the chair. We also show that it is possible to monitor body movements on the opposite side of a wall to the sensor. These sensing techniques have biomedical applications for non-contact monitoring of electrophysiological conditions and can be applied to passive through-the-wall surveillance systems for security applications.

1. Introduction

The term biodynamic activity is broadly used to describe the study of physical motion or dynamics in living systems. Most biodynamic activity is associated with electrical properties whether by virtue of it being electrophysiological or dielectric in nature. Electrophysiology describes the changes in electric potential which occur within the body as a result of the various biochemical functions and this can be measured as spatial-temporal changes in voltages or currents on the surface of the body. Conventional electrophysiology uses Ag/AgCl electrodes which are placed in direct electrical contact with the skin. These electrodes have a low impedance cutaneous contact. They operate as transducers converting ionic current from the body into electron current which is then electronically amplified. The electric potential sensor (EPS) requires no cutaneous electrical contact. It is configured to be in electrical isolation from the skin via a thin insulator. Changes in voltage on the surface of the skin are monitored by sensing the displacement current via a strong capacitive coupling. The EPS has been applied successfully to the non-invasive monitoring of high resolution electrophysiological signals. The collection of the electrocardiogram (ECG) [1, 2], electroencephalogram (EEG) [3] and electro-oculogram (EOG) [4] has been demonstrated. It is also possible to use the EPS as an electric field sensor to detect electrophysiological signals remotely, without any electrical or physical contact to the

body. In this (remote) configuration, the EPS is weakly coupled to the signal source with an air-gap between the source and sensor. Cardiac activity has been detected at distances of up to 1 m from the body [5] and the EEG has been monitored with a 3 mm air-gap between the sensor and the head [3].

In this paper we extend the remote sensing work to show that it is now possible to apply the EPS more generally to the remote monitoring of biodynamic activity. In this context, and in a static or dynamically changing electric field, changes in properties of a dielectric whether geometrical (size and shape), spatial (position) or physical (permittivity) will be reflected in the temporal changes in displacement current between the source and sensor. We demonstrate that the electric potential sensor can be successfully used for the remote sensing and monitoring of bioelectric activity. We show examples of heart-rate measurements taken from a seated subject using sensors mounted in the chair. We also show that it is possible to monitor body movements on the opposite side of a wall to the sensor. These sensing techniques have biomedical applications for non-contact monitoring of electrophysiological conditions and can be applied to passive through-the-wall surveillance systems for security applications.

2. The electric potential sensor

Electric potential sensors have been used for many years in laboratory applications e.g. in studies of non-invasive imaging of signals in digital circuits [6] and for the study of dielectric structures at the micron resolution level [7]. A block diagram of a typical electric potential sensor probe is shown in figure 1. The probe consists of a sensor electrode acting as the displacement current input to an ultra high input impedance electrometer amplifier. The amplifier design uses guarding and novel feedback techniques to enhance the input impedance, reduce the input capacitance and to maintain electronic stability of the sensor [8]. A photograph of a typical EPS as used for this work is shown in figure 2. The electronics is housed in a cylindrical can approximately 9 cm long and 3.5 cm in diameter. The sensor electrode diameter is 2.5 cm. Details of circuit design, construction and specification have been reported elsewhere [5, 8]. The voltage outputs from the sensors are fed to an analogue processor where the signals are amplified and band-pass filtered. The output of the processor is fed to a commercial PCMCIA analogue to digital converter interface card and the data is acquired on a laptop computer. Display and storage of the digital data is controlled using a graphical user interface, generated using LabVIEW[®] [9] software.

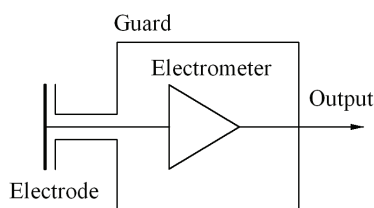


Figure 1. Block diagram of a typical EPS sensor probe showing the sensor electrode and the electrometer amplifier.



Figure 2. Photograph of a typical EPS sensor probe. Approx. 9 cm long and 3.5 cm diameter. The sensor electrode diameter is 2.5 cm.

3. Results

An example of the application of the EPS technology applied to the remote sensing of cardiac activity is shown in figure 3. Two sensors were placed inside the back of a chair with approximately 3mm of material and a 2 cm air-gap providing the coupling medium for the displacement current from the seated subject. The sensors were configured as a differential pair to provide rejection of unwanted noise sources and the resultant ECG is as shown. The heartbeat is clearly seen. The QRS-complex can be identified and the signal-to-noise ratio (SNR) is sufficient for threshold analysis to be applied in order to compute successive R-R intervals (the time periods between sequential QRS-complexes). The heart rate variability (HRV) is plotted in figure 4 with sufficient accuracy to identify the small changes

in heartbeat rate which occur during the respiratory cycle. The subject was seated and at rest in this example resulting in a low heartbeat rate (~ 65 to 70 bpm). The low frequency modulation shown in figure 4 is due to respiration.

The detection of the movement of large dielectric masses is illustrated in the example shown in figure 5. Here, a single EPS was positioned facing a brick wall (~ 10 cm sensor to wall distance) which separated a laboratory from a corridor. The EPS was able to detect when people were passing by on the other side of the wall. The signature for a single person walking by is shown in figure 5. The

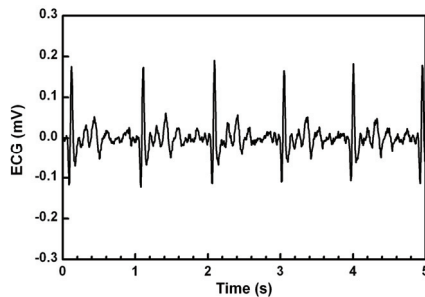


Figure 3. An ECG as collected using a pair of EPS sensors mounted in the back of a chair.

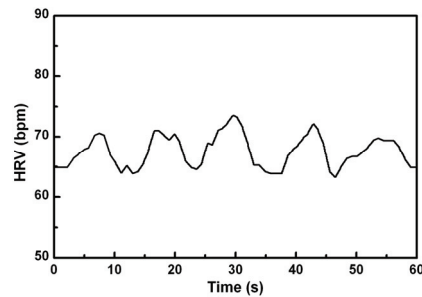


Figure 4. ECG data from figure 1 plotted as heart rate variability. The low frequency modulation is due to respiration.

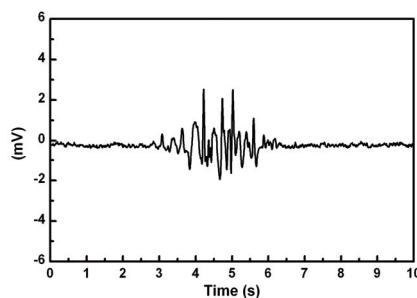


Figure 5. Signature from the remote sensing of human body movement using the EPS as a 'through-the-wall surveillance' device.

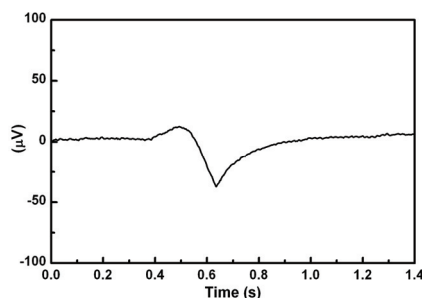


Figure 6. Signature obtained using the EPS to detect the remote sensing of water droplets in free fall movement.

large body mass (mainly water) of the human moving through the ambient electric field caused enough perturbation in the field to induce changes in the displacement current. By increasing the electronic gain of the sensor the sensitivity may be increased to enable very small dielectric masses to be detected. Figure 6 shows the signature obtained from a single droplet of water in free fall movement approximately 1 m away from the sensor.

The EPS signal shown in Figure 5 is of a biodynamic nature and is electrical. Environmental monitoring in the proximity of the EPS, while monitoring the electric field, shows that there is no contribution to the signal from acoustics or floor vibration. The data in Figure 7 demonstrates this by showing the result of monitoring changes in sound pressure level (SPL) and floor vibration at the same time as monitoring the EPS signal. The temporal variations in signal levels (from a stable background level) for the EPS, SPL and vibration monitor occur as a result of 4 discrete events indicated 1 to 4 in Figure 7(a). The EPS signal is shown plotted in Figure 7(a) and the sequence of actions by a test subject are as follows. Event 1 is due to general movement in the room including stamping of feet to check instrumental operation. At event 2 the subject leaves the room, slams the door and walks along the corridor away from the sensing area. Events 3 and 4 correspond to the subject walking up and down the corridor passing the sensing area twice. The data in Figure 7 shows the absence of any variation in SPL or floor vibration in the proximity of the EPS during the periods of EPS detection of body movement on the opposite side of the wall (i.e. in periods when events 3 and 4 occur).

4. Conclusions

In this paper we have demonstrated that EPS can be successfully used for the remote sensing and monitoring of bioelectric activity. We have shown that it is possible to perform remote sensing of the human heartbeat using sensors installed in the back of a chair. The sensitivity and fidelity of the ECGs obtained are adequate to provide HRV information to the degree that the respiration rate can be observed. We have also shown that it is possible to use these sensors to detect movement of people on the opposite side of a brick wall and that the sensitivity of the technique is sufficient to detect a single droplet of water in free fall movement at a distance of 1 m from the sensor.

These techniques are completely passive, and could be used covertly. The sensing of the ambient electric field introduces no other signal which could be used to determine if the EPS is being used in that environment. We suggest that these techniques would be most suitable for biomedical and security applications and may well be a candidate for 'through-the-wall surveillance' (TWS) technologies.

Acknowledgments

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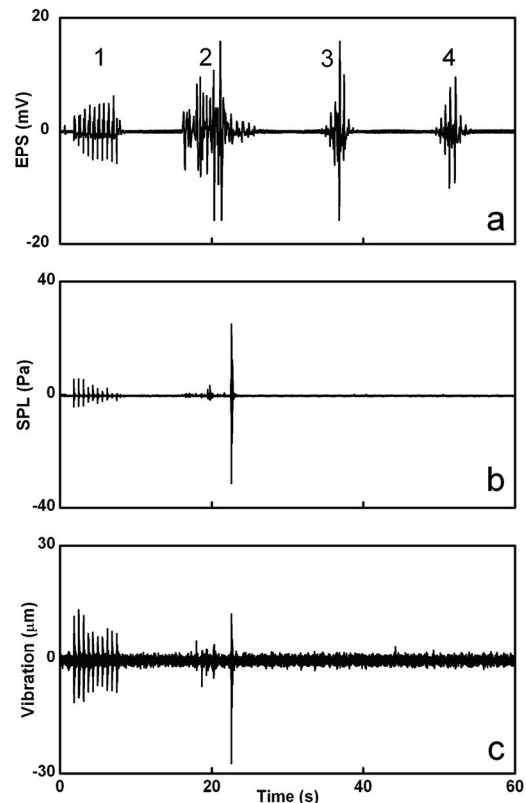


Figure 7. Simultaneous monitoring of changes in (a) electric field using an EPS, (b) SPL and (c) floor vibration. The data corresponds to variations as a subject passes on the opposite side of a wall (see text for explanation).